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Sun et al.

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(54) HALL EFFECT SENSOR DEVICES AND METHODS OF FORMING HALL EFFECT SENSOR DEVICES

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G01R 33/00	(2006.01)
H01L 43/14	(2006.01)
H01L 43/06	(2006.01)
H01L 43/04	(2006.01)

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CPC ***G01R 33/07*** (2013.01); ***G01R 33/0052*** (2013.01); ***H01L 43/04*** (2013.01); ***H01L 43/065*** (2013.01); ***H01L 43/14*** (2013.01)

(58) **Field of Classification Search**
CPC G01R 33/07; G01R 33/0052; H01L 43/14; H01L 43/065; H01L 43/04
See application file for complete search history.

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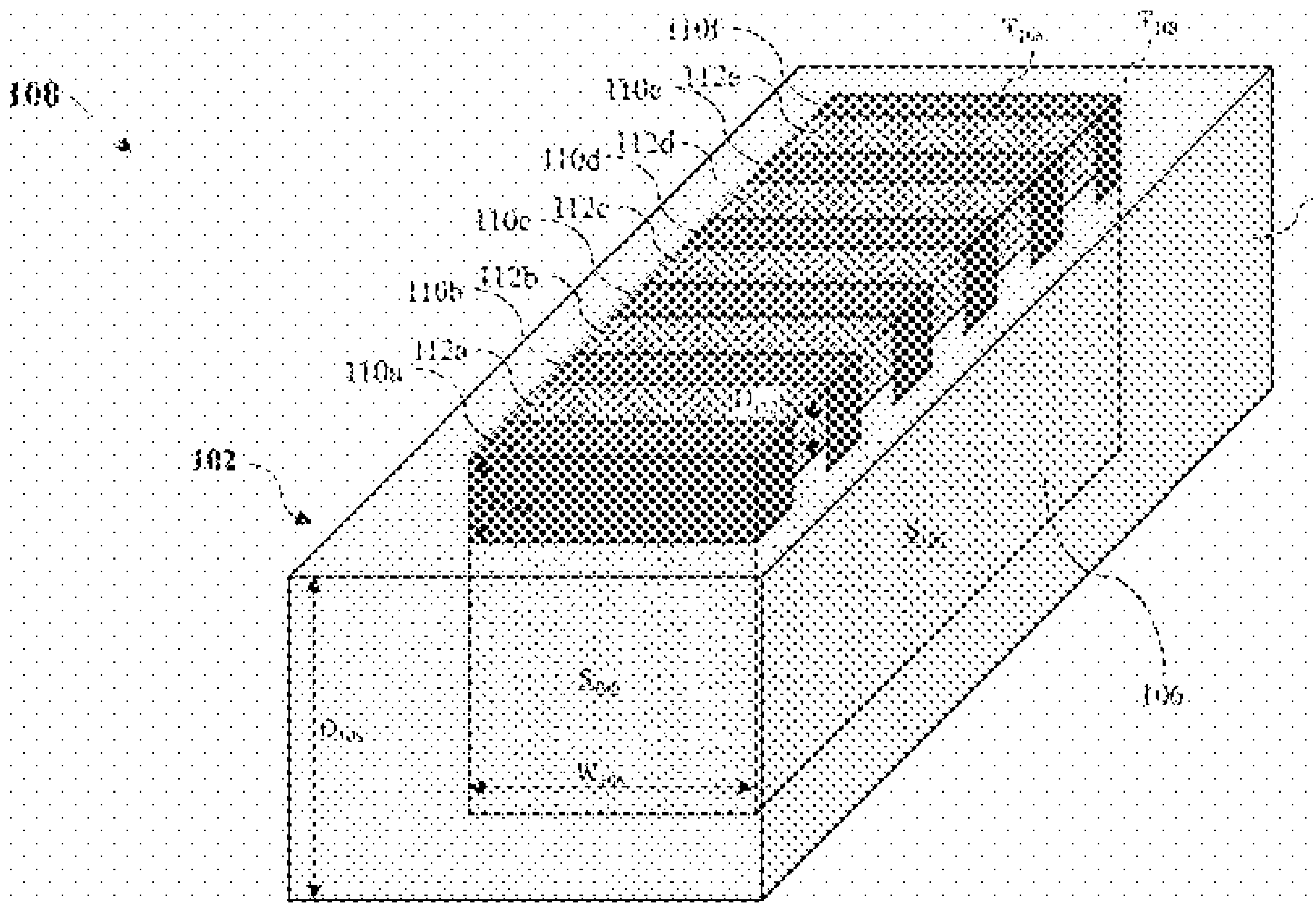
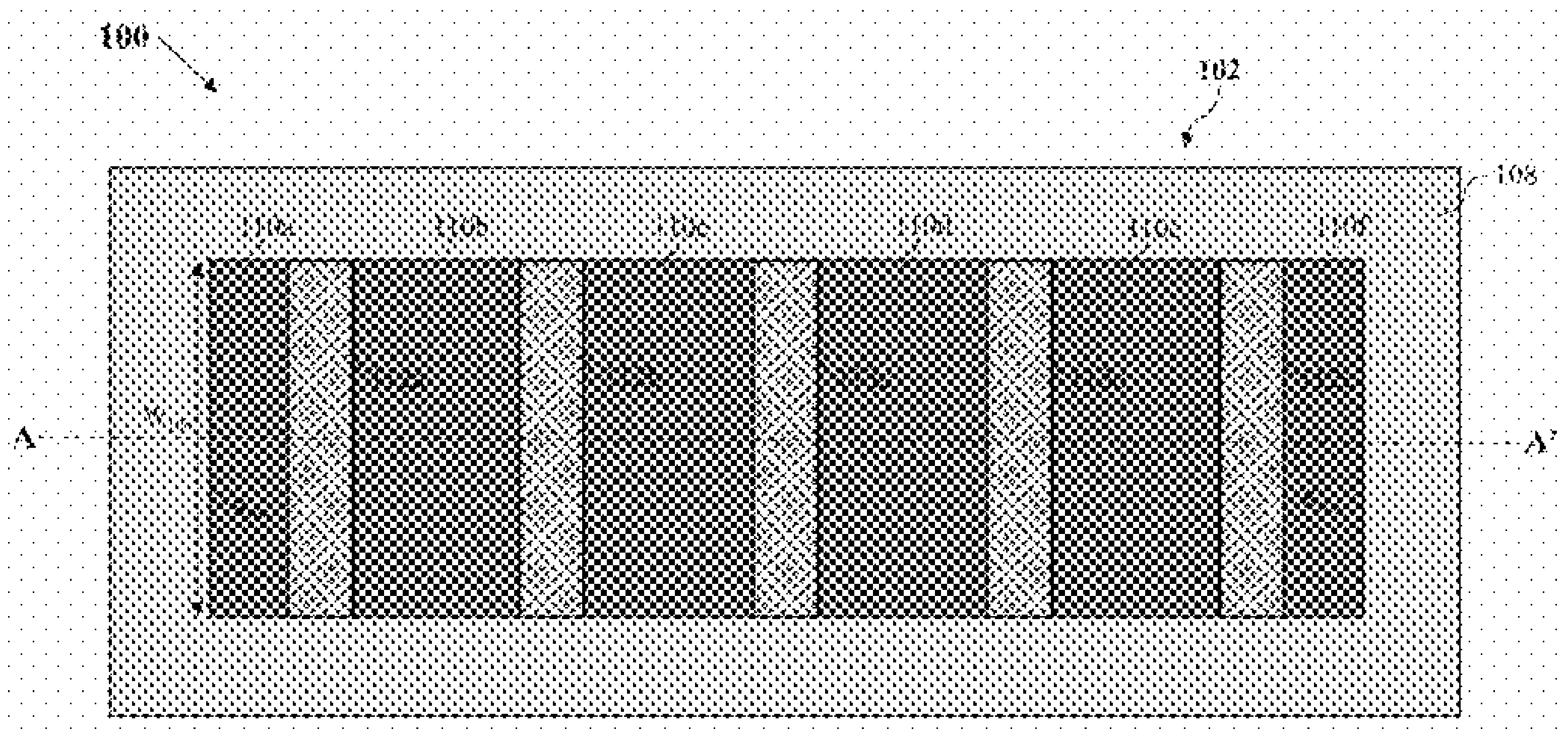
(74) *Attorney, Agent, or Firm* — Viering Jentschura & Partner mbB

(57) ABSTRACT

A Hall effect sensor device may be provided, including one or more sensor structures. Each sensor structure may include: a base layer having a first conductivity type; a Hall plate region having a second conductivity type opposite from the first conductivity type arranged above the base layer; a first isolating region arranged around and adjoining the Hall plate region, and contacting the base layer; a plurality of second isolating regions arranged within the Hall plate region; and a plurality of terminal regions arranged within the Hall plate region. The first and second isolating regions may include electrically insulating material, and each neighboring pair of terminal regions may be electrically isolated from each other by one of the second isolating regions.

20 Claims, 10 Drawing Sheets





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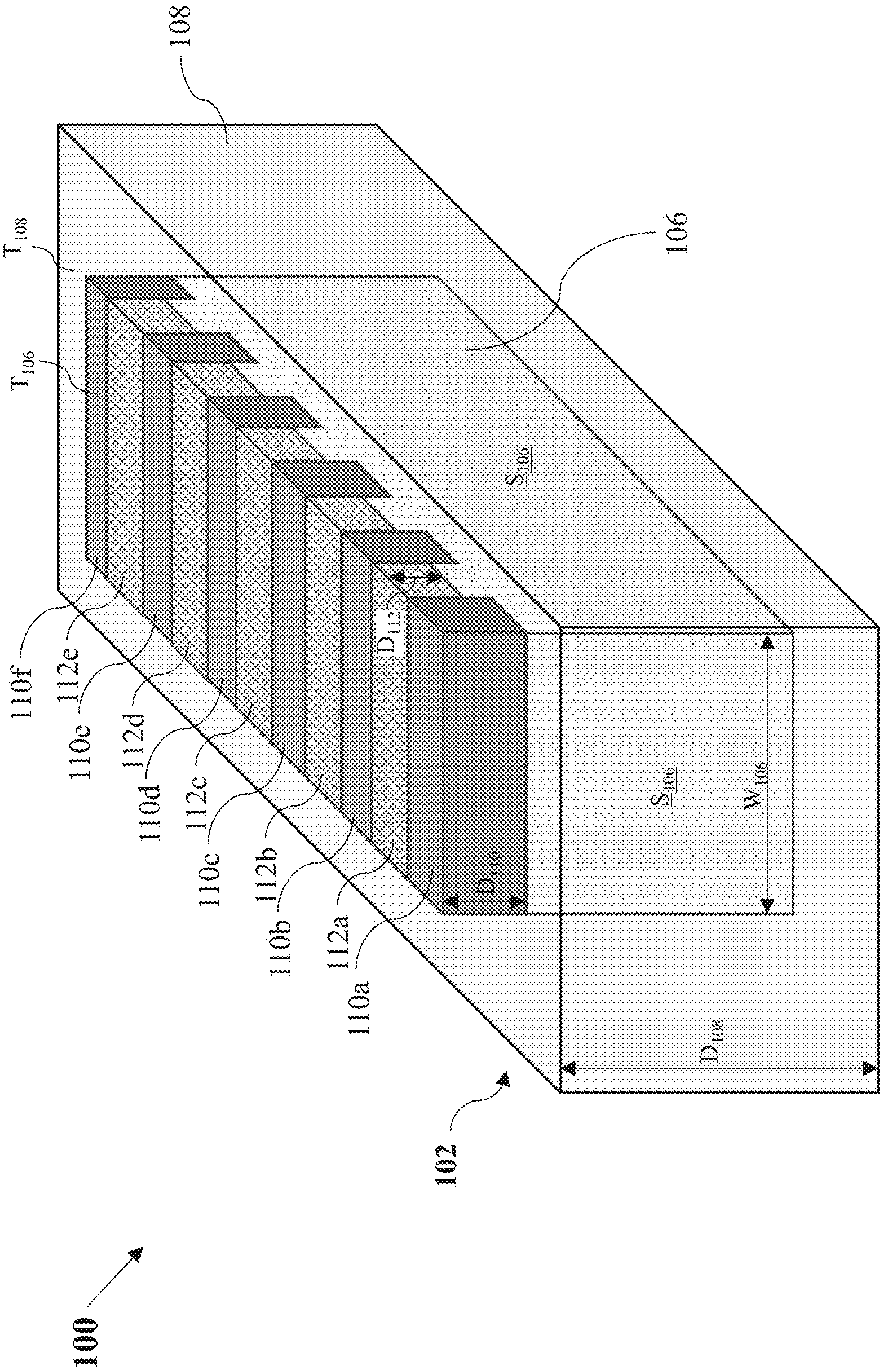
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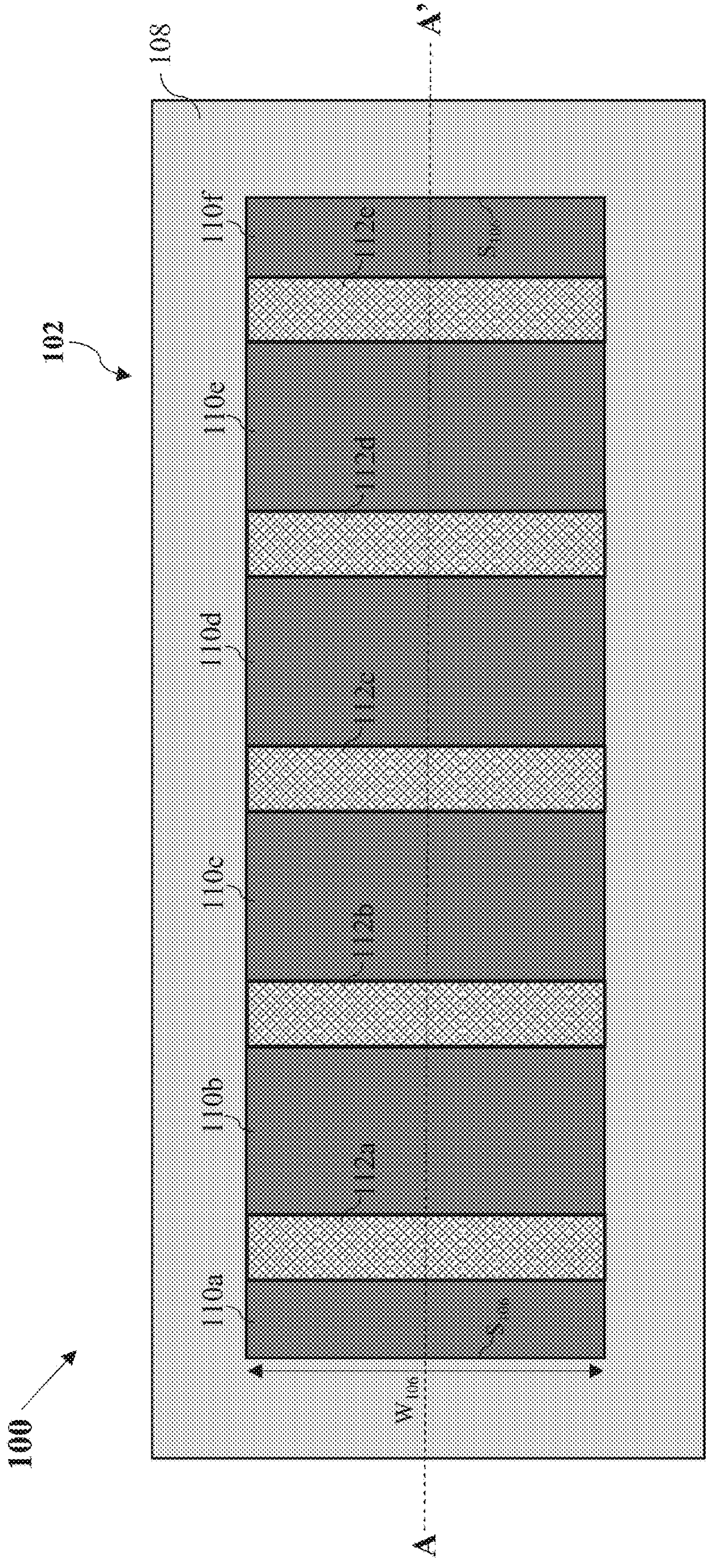
106
T_{108}
T_{106}
S_{106}
D_{112}
110f
112e
110e
112d
110d
112c
110c
112b
110b
112a
110a
D_{110}
S_{106}
W_{106}
D_{108}
102
100

FIG. 1A


A'
108
102
110f
112e
S110
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110b
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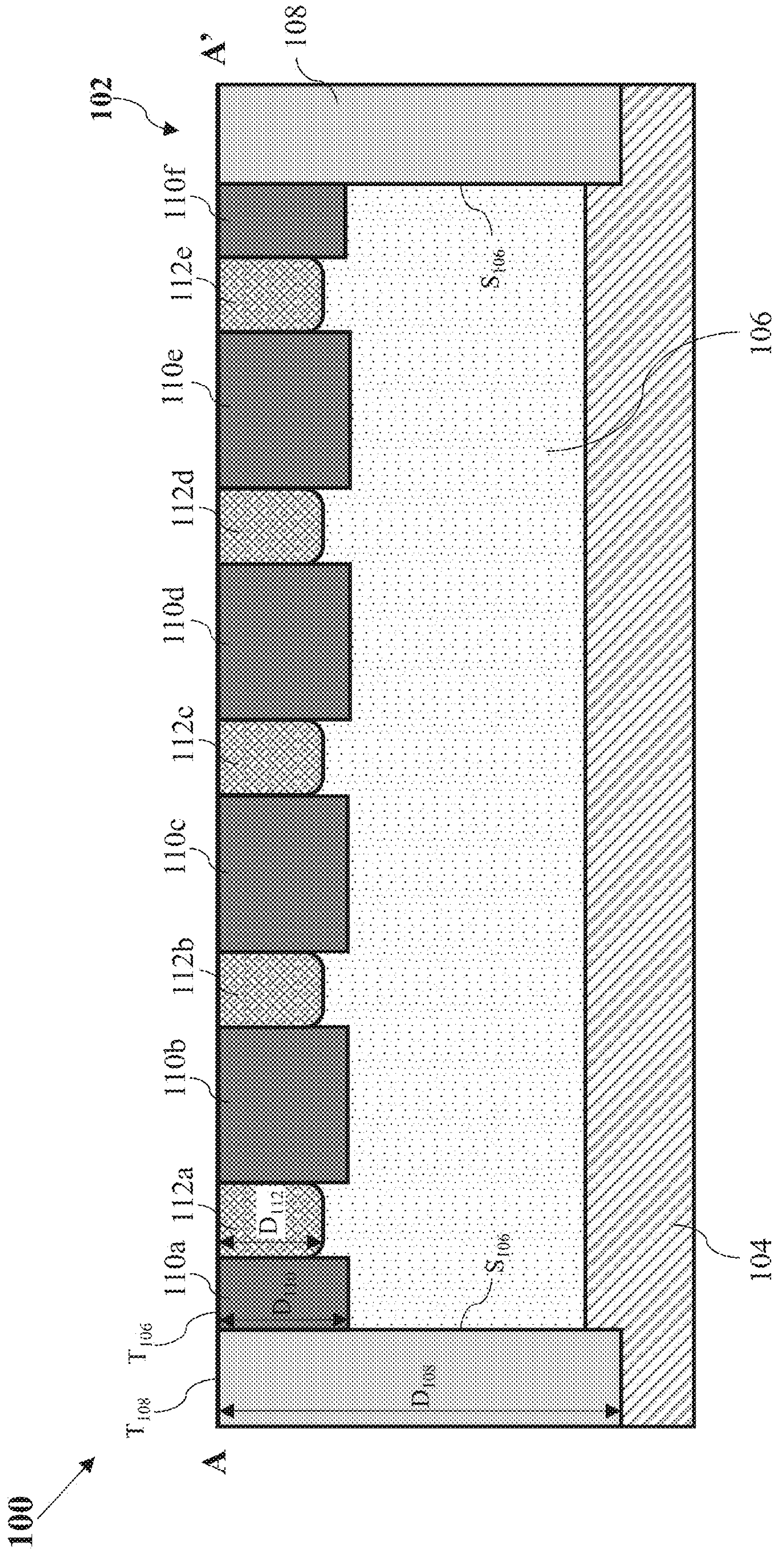
110a
S110
W106
100
A

FIG. 1B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102
A
A'
T_{108}
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D_{108}
D_{110}
D_{112}
108
110a
112a
110b
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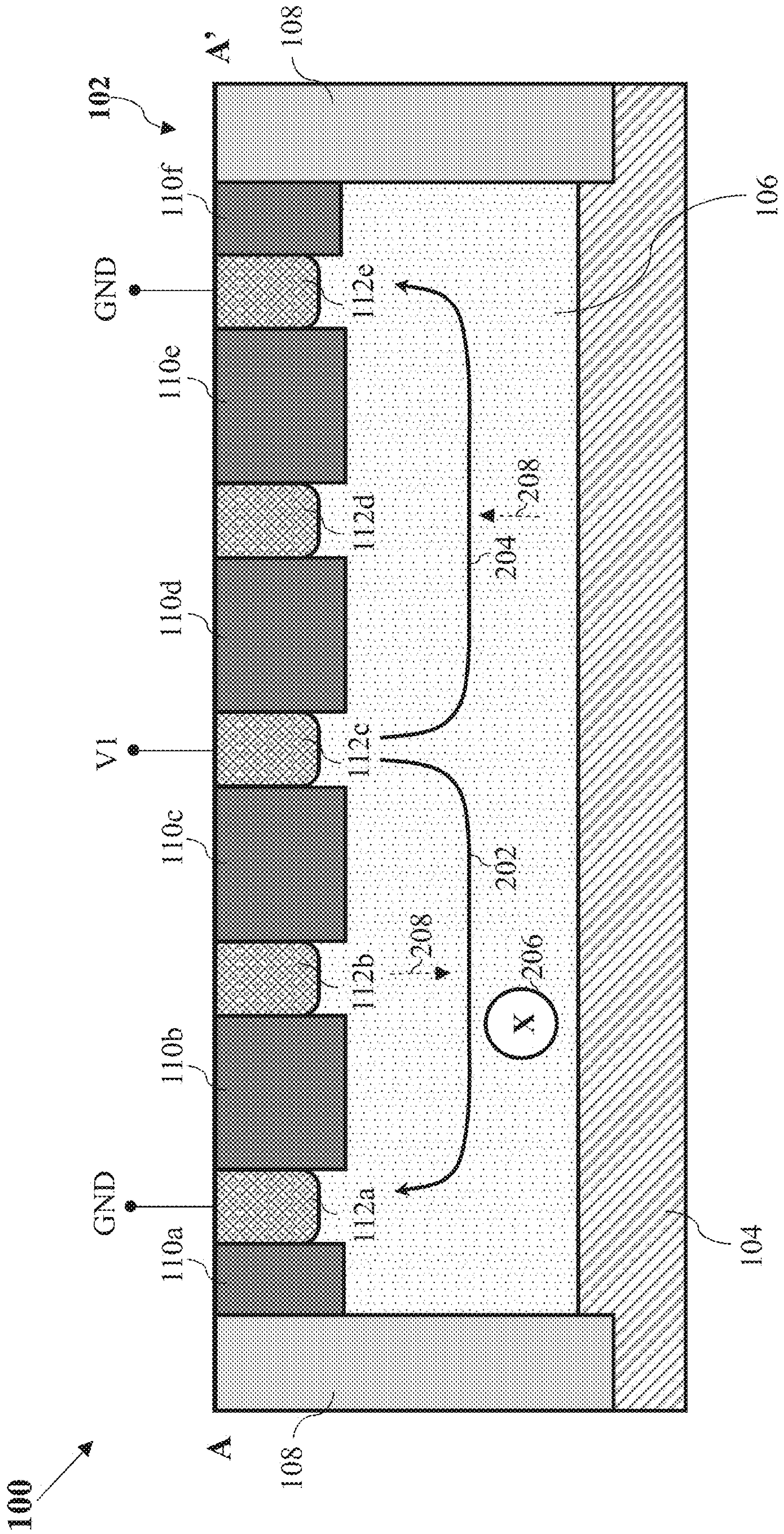
110d
112d
110e
112e
110f
S_{106}
S_{106}
106
104

FIG. 1C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A
108
110a
GND
112a
110b
112b
208
206
X
202
110c
V1
112c
110d
112d
204
208
110e
GND
112e
110f
102
A'
108
106
104

FIG. 2

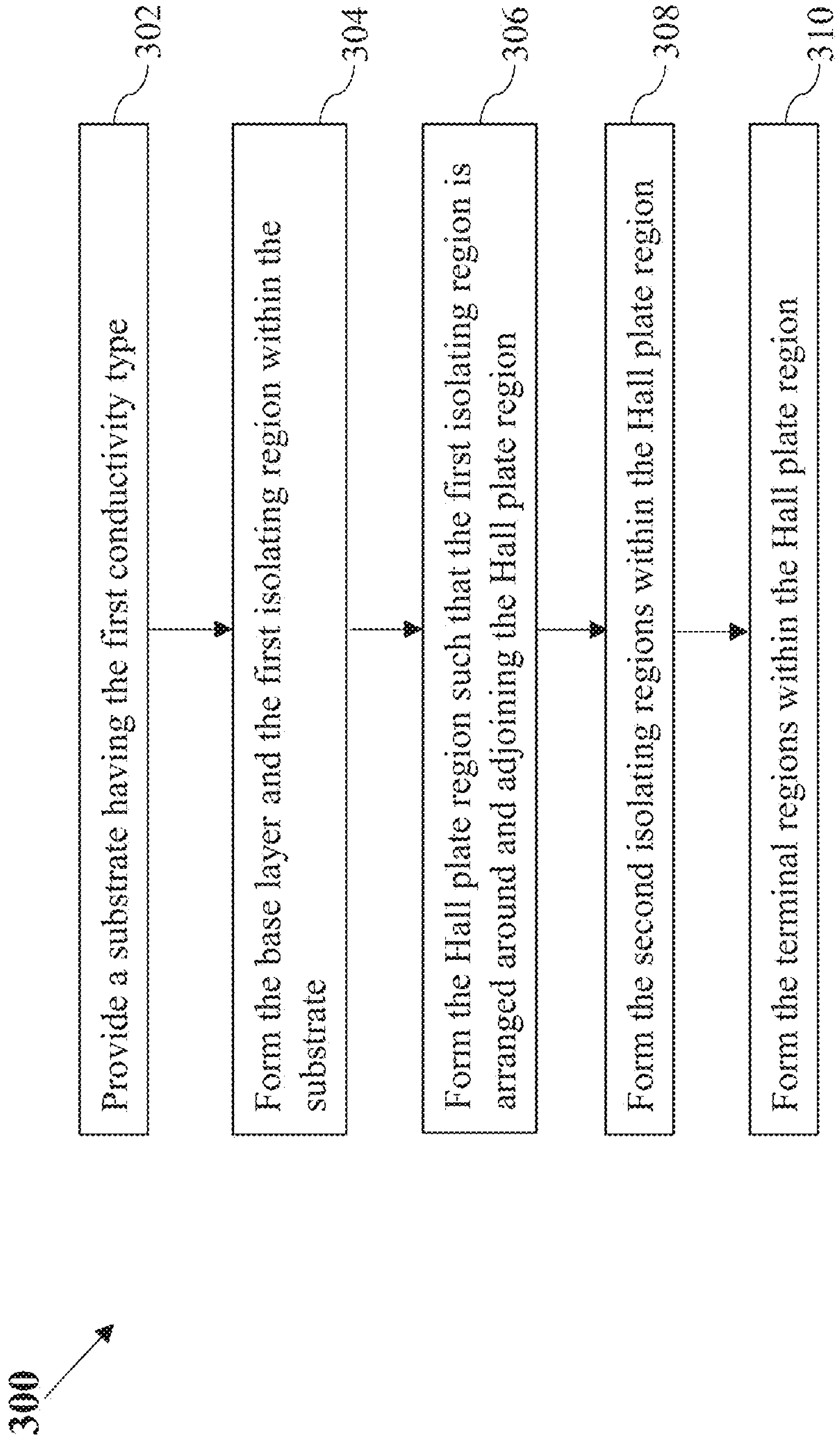
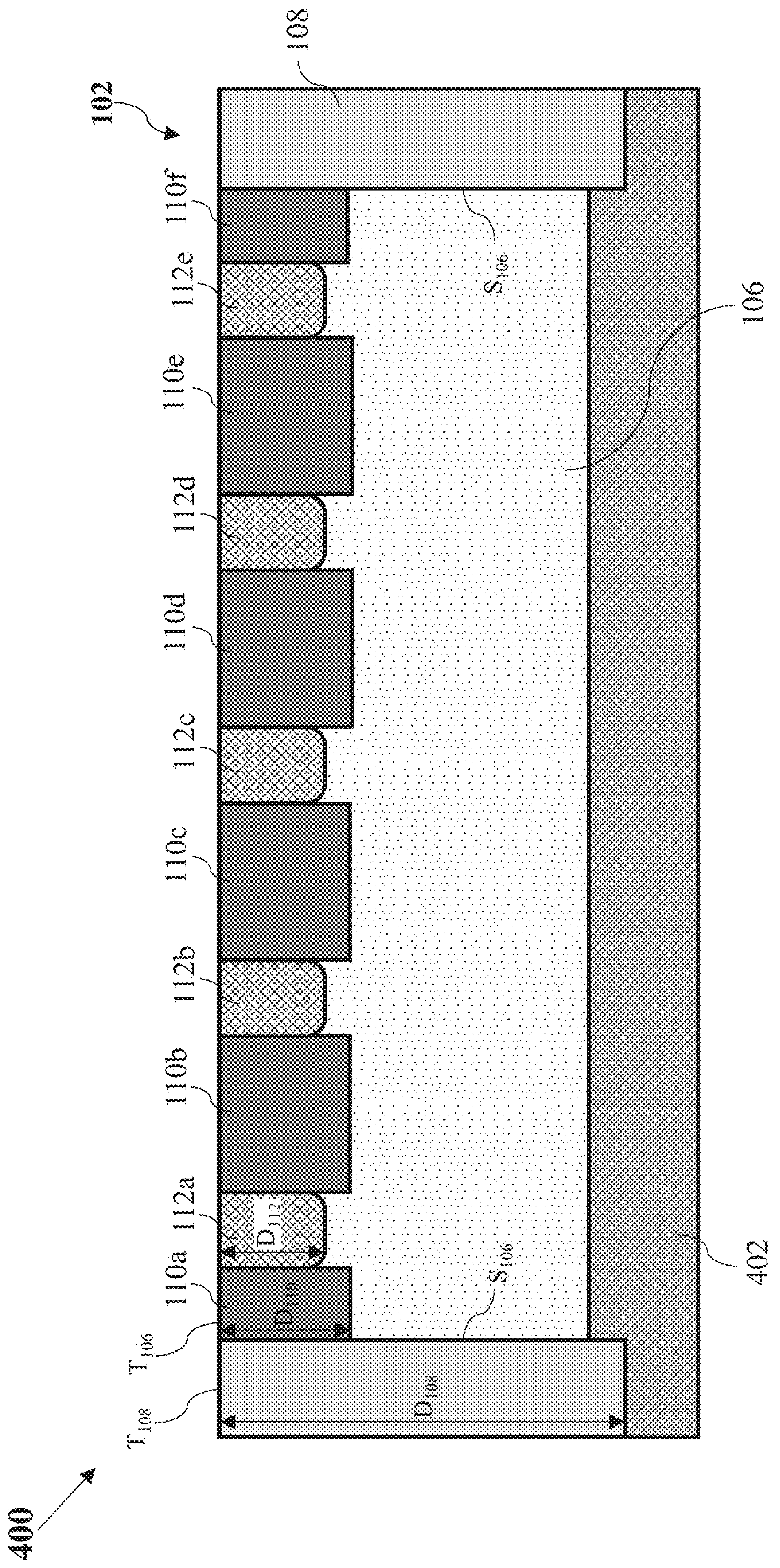

300
302
Provide a substrate having the first conductivity type
304
Form the base layer and the first isolating region within the substrate
306
Form the Hall plate region such that the first isolating region is arranged around and adjoining the Hall plate region
308
Form the second isolating regions within the Hall plate region
310
Form the terminal regions within the Hall plate region

FIG. 3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108
110f
112e
110e
112d
110d
112c
110c
112b
110b
112a
110a
T_{106}
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D_{112}
D_{110}
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S_{106}
S_{106}
106
402

FIG. 4

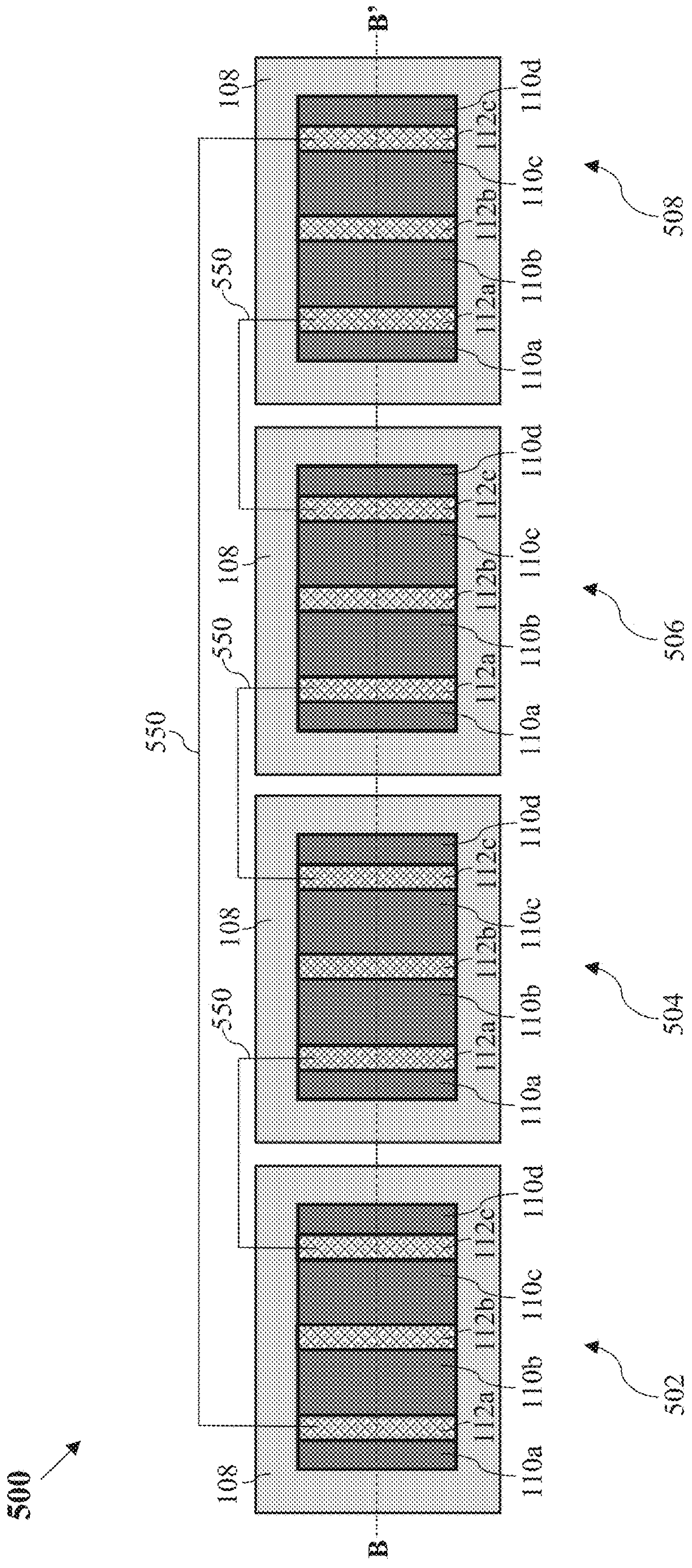
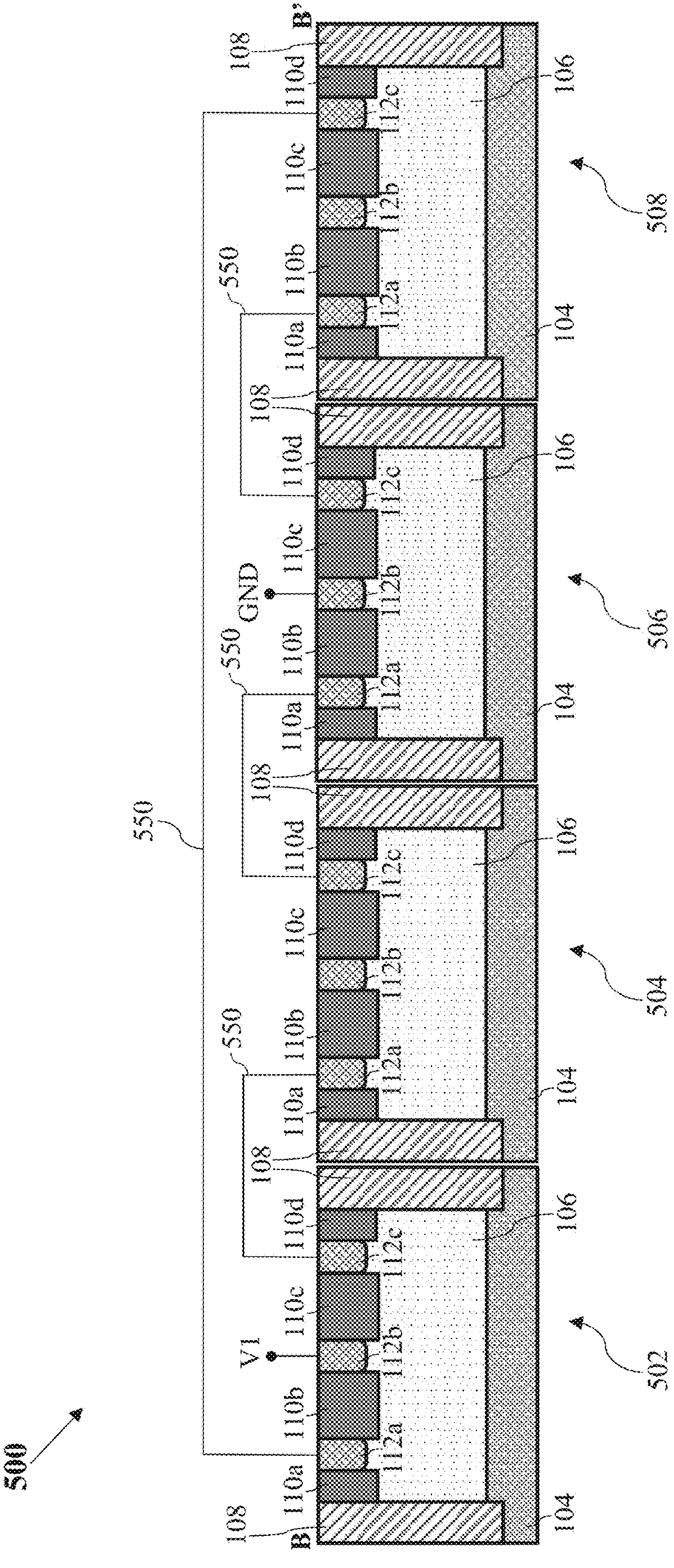

500
B
B'
108
110a
112a
110b
112b
110c
112c
110d
550
502
504
506
508

FIG. 5A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B
B'
108
110a
110b
110c
110d
112a
112b
112c
104
106
550
V1
GND
502
504
506
508

FIG. 5B

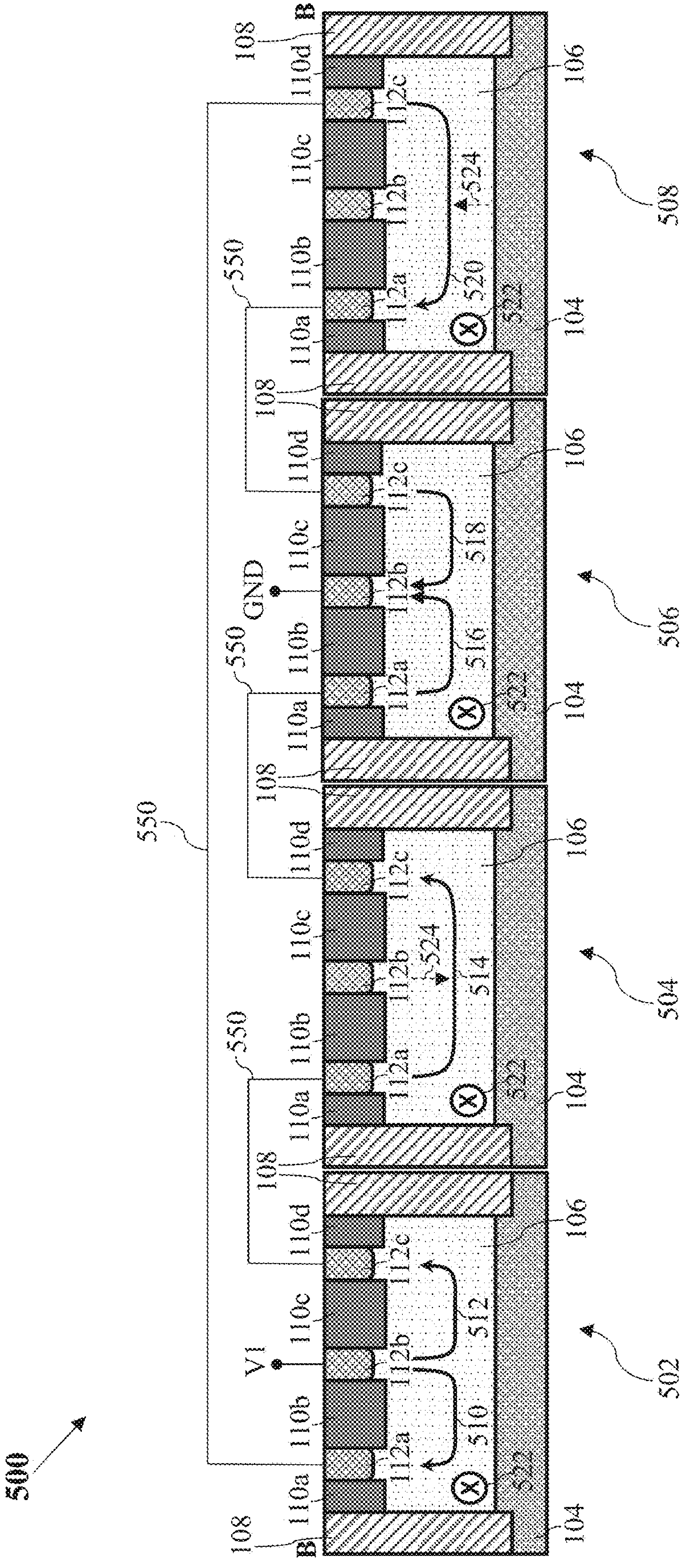
500
B
B'
108
110a
110b
110c
110d
112a
112b
112c
104
106
502
504
506
508
510
512
514
516
518
520
522
524
550
V1
GND
X

FIG. 6

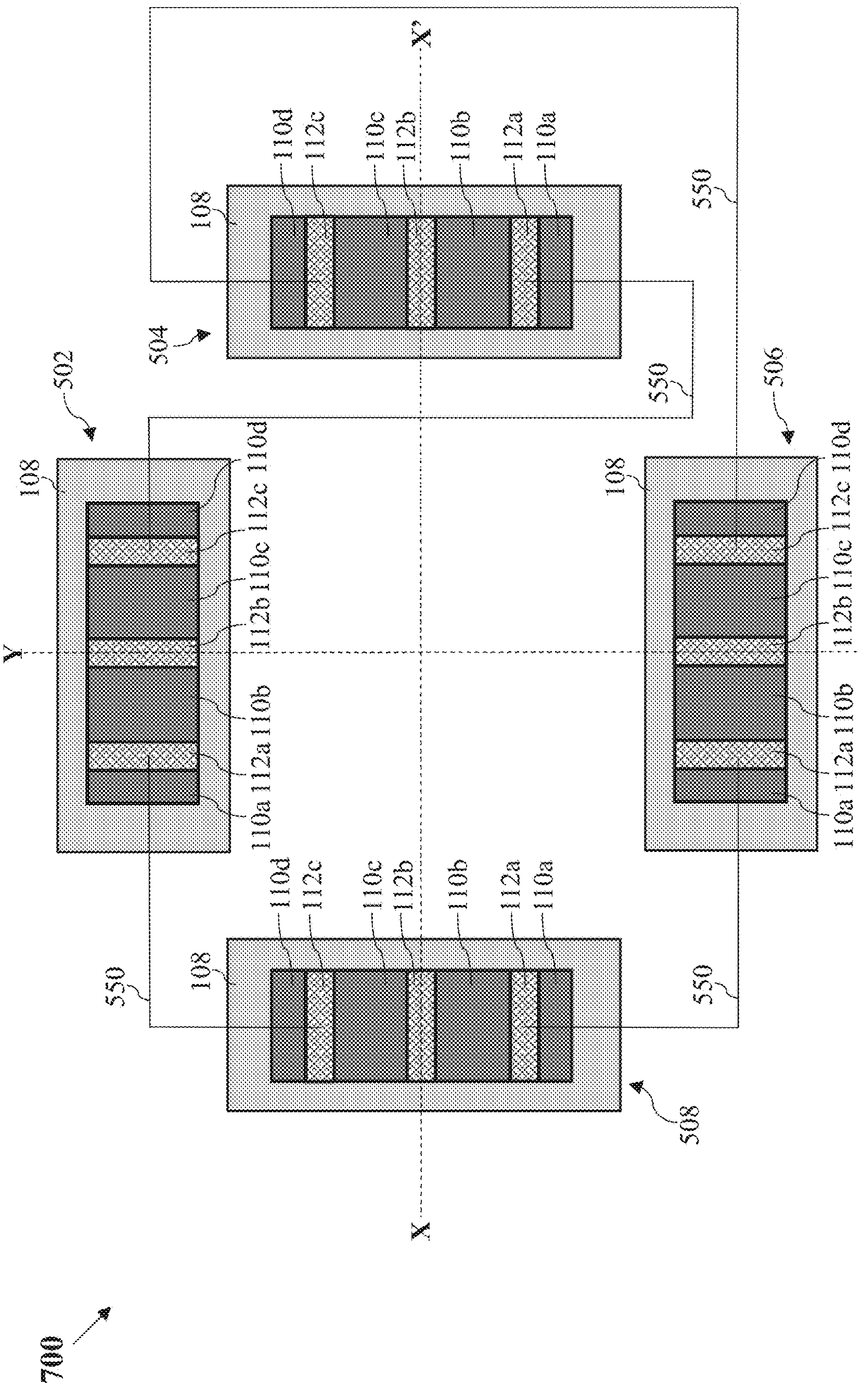
700
502
504
506
508
108
108
108
108
550
550
550
550
110a
110b
110c
110d
112a
112b
112c
110a
110b
110c
110d
112a
112b
112c
110a
110b
110c
110d
112a
112b
112c
110a
110b
110c
110d
112a
112b
112c
X
X'
Y
Y'

FIG. 7

HALL EFFECT SENSOR DEVICES AND METHODS OF FORMING HALL EFFECT SENSOR DEVICES

TECHNICAL FIELD

The present disclosure relates generally to Hall effect sensor devices, and methods of forming the Hall effect sensor devices.

BACKGROUND

Hall effect sensor devices capable of determining magnetic field strengths are used in various applications, such as automotive applications. A Hall effect sensor device generally includes a Hall plate of electrically conducting material and terminals connected to the Hall plate. External voltages may be applied to the terminals to cause electric currents to flow through the Hall plate. In the presence of a magnetic field perpendicular to the plane of the Hall plate, Lorentz forces may be exerted on the charge carriers in the electric currents. This may produce a Hall voltage within the Hall plate. By determining the magnitude of the Hall voltage, the strength of the magnetic field may be determined.

Hall effect sensor devices can be implemented as semiconductor devices, with the Hall plates and terminals including doped semiconductor material. In several existing Hall effect sensor devices, an intermediate region may be arranged between each neighboring pair of terminals. This intermediate region may also include doped semiconductor material, but of a conductivity type opposite to that of the Hall plate and the terminals. This gives rise to the presence of many p-n junctions within the Hall plate. The depletion widths of these p-n junctions may vary based on the external voltages applied to the terminals and the temperature around the Hall plate. For example, these depletion widths may increase when higher external voltages are applied to the terminals. Further, the variations in the depletion widths may differ across different p-n junctions. As a result, there may be resistance mismatch between different regions of the Hall plate. Therefore, the signal-to-noise ratios (SNRs) and the offset/residual voltages (in other words, the Hall voltages produced in the absence of magnetic fields) of existing Hall effect sensor devices are generally high.

SUMMARY

According to various non-limiting embodiments, there may be provided a Hall effect sensor device including a sensor structure, wherein the sensor structure may include: a base layer having a first conductivity type; a Hall plate region having a second conductivity type opposite from the first conductivity type arranged above the base layer; a first isolating region arranged around and adjoining the Hall plate region, wherein the first isolating region may include an electrically insulating material and may contact the base layer; a plurality of second isolating regions arranged within the Hall plate region, wherein each of the plurality of second isolating regions may include an electrically insulating material; and a plurality of terminal regions arranged within the Hall plate region, each neighboring pair of terminal regions electrically isolated from each other by one of the plurality of second isolating regions.

According to various non-limiting embodiments, there may be provided a method of forming a Hall effect sensor device including: providing a substrate having a first conductivity type; forming a base layer having the first conductivity type and a first isolating region including an electrically insulating material within the substrate, wherein the first isolating region may contact the base layer; forming a Hall plate region having a second conductivity type opposite from the first conductivity type above the base layer, wherein the first isolating region may be arranged around and adjoining the Hall plate region; forming a plurality of second isolating regions within the Hall plate region, wherein each of the plurality of second isolating regions may include an electrically insulating material; and forming a plurality of terminal regions within the Hall plate region, each neighboring pair of terminal regions electrically isolated from each other by one of the plurality of second isolating regions.

According to various non-limiting embodiments, there may be provided a Hall effect sensor device including a sensor structure, wherein the sensor structure may include: an insulating layer; a Hall plate region arranged above the insulating layer; a first isolating region arranged around and adjoining the Hall plate region, wherein the first isolating region may include an electrically insulating material and may contact the insulating layer; a plurality of second isolating regions arranged within the Hall plate region, wherein each of the plurality of second isolating regions may include an electrically insulating material; and a plurality of terminal regions arranged within the Hall plate region, each neighboring pair of terminal regions electrically isolated from each other by one of the plurality of second isolating regions.

BRIEF DESCRIPTION OF THE DRAWINGS

In the drawings, like reference characters generally refer to the same parts throughout the different views. Also, the drawings are not necessarily to scale, emphasis instead generally being placed upon illustrating the principles of the invention. Non-limiting embodiments of the invention will now be illustrated for the sake of example only with reference to the following drawings, in which:

FIGS. **1**A, **1**B and **1**C respectively show a simplified perspective view, a simplified top view and a simplified cross-sectional view of a Hall effect sensor device according to various non-limiting embodiments;

FIG. **2** shows the Hall effect sensor device of FIGS. **1**A to **1**C in use;

FIG. **3** shows a flow chart illustrating a method of forming the Hall effect sensor device of FIGS. **1**A to **1**C;

FIG. **4** shows a simplified cross-sectional view of a Hall effect sensor device according to alternative non-limiting embodiments;

FIGS. **5**A and **5**B respectively show a simplified top view and a simplified cross-sectional view of a Hall effect sensor device according to alternative non-limiting embodiments;

FIG. **6** shows the Hall effect sensor device of FIGS. **5**A and **5**B in use; and

FIG. **7** shows a simplified top view of a Hall effect sensor device according to alternative non-limiting embodiments.

DETAILED DESCRIPTION

The embodiments generally relate to semiconductor devices. More particularly, some embodiments relate to sensor devices including Hall effect sensor devices. The sensor devices may be used for sensing magnetic fields and may be used in various industries, such as, but not limited to, the automotive industry for position measurements.

Aspects of the present invention and certain features, advantages, and details thereof, are explained more fully below with reference to the non-limiting examples illustrated in the accompanying drawings. Descriptions of well-known materials, fabrication tools, processing techniques, etc., are omitted so as not to unnecessarily obscure the invention in detail. It should be understood, however, that the detailed description and the specific examples, while indicating aspects of the invention, are given by way of illustration only, and are not by way of limitation. Various substitutions, modifications, additions, and/or arrangements, within the spirit and/or scope of the underlying inventive concepts will be apparent to those skilled in the art from this disclosure.

Approximating language, as used herein throughout the specification and claims, may be applied to modify any quantitative representation that could permissibly vary without resulting in a change in the basic function to which it is related. Accordingly, a value modified by a term or terms, such as "approximately", "about," is not limited to the precise value specified. In some instances, the approximating language may correspond to the precision of an instrument for measuring the value. Further, a direction is modified by a term or terms, such as "substantially" to mean that the direction is to be applied within normal tolerances of the semiconductor industry. For example, "substantially parallel" means largely extending in the same direction within normal tolerances of the semiconductor industry and "substantially perpendicular" means at an angle of ninety degrees plus or minus a normal tolerance of the semiconductor industry.

The terminology used herein is for the purpose of describing particular examples only and is not intended to be limiting of the invention. As used herein, the singular forms "a", "an" and "the" are intended to include the plural forms as well, unless the context clearly indicates otherwise. It will be further understood that the terms "comprise" (and any form of comprise, such as "comprises" and "comprising"), "have" (and any form of have, such as "has" and "having"), "include"(and any form of include, such as "includes" and "including"), and "contain" (and any form of contain, such as "contains" and "containing") are open-ended linking verbs. As a result, a method or device that "comprises," "has," "includes" or "contains" one or more steps or elements possesses those one or more steps or elements, but is not limited to possessing only those one or more steps or elements. Likewise, a step of a method or an element of a device that "comprises," "has," "includes" or "contains" one or more features possesses those one or more features, but is not limited to possessing only those one or more features. Furthermore, a device or structure that is configured in a certain way is configured in at least that way, but may also be configured in ways that are not listed.

As used herein, the term "connected," when used to refer to two physical elements, means a direct connection between the two physical elements. The term "coupled," however, can mean a direct connection or a connection through one or more intermediary elements.

As used herein, the terms "may" and "may be" indicate a possibility of an occurrence within a set of circumstances; a possession of a specified property, characteristic or function; and/or qualify another verb by expressing one or more of an ability, capability, or possibility associated with the qualified verb. Accordingly, usage of "may" and "may be" indicates that a modified term is apparently appropriate, capable, or suitable for an indicated capacity, function, or usage, while taking into account that in some circumstances the modified term may sometimes not be appropriate, capable or suitable. For example, in some circumstances, an event or capacity can be expected, while in other circumstances the event or capacity cannot occur—this distinction is captured by the terms "may" and "may be."

FIG. **1**A shows a simplified perspective view of a Hall effect sensor device **100** according to various non-limiting embodiments. FIG. **1**B shows a simplified top view of the device **100** and FIG. **1**C shows a cross-sectional view of the device **100** along the line A-A' of FIG. **1**B. The device **100** may be a vertical Hall effect sensor device **100** and may include a single sensor structure **102**.

As shown in FIG. **1**C, the sensor structure **102** may include a base layer **104**. The base layer **104** may include a semiconductor substrate, such as a silicon substrate. Other types of semiconductor substrates, such as a silicon germanium substrate, may also be used. The base layer **104** may have a first conductivity type, where the first conductivity type may be p-type or n-type. For example, the base layer **104** may include a p-type substrate or an n-type substrate. Note that for simplicity, the base layer **104** is not shown in FIG. **1**A.

The sensor structure **102** may further include a substantially rectangular Hall plate region **106** arranged above the base layer **104**. The Hall plate region **106** may alternatively be referred to as the sensor body. The Hall plate region **106** may have a single conductivity type. For example, the Hall plate region **106** may have a second conductivity type opposite from the first conductivity type. The second conductivity type may be p-type or n-type. By configuring the base layer **104** and the Hall plate region **106** such that they may include dopants of opposite conductivity types, current flow from the Hall plate region **106** through the base layer **104** may be minimized (and in one non-limiting example, may be fully restricted).

The sensor structure **102** may further include a first isolating region **108** arranged above the base layer **104** around the Hall plate region **106**. The first isolating region **108** may adjoin the Hall plate region **106** and may contact the base layer **104**. As shown in FIG. **1**C, the first isolating region **108** may extend partially into the base layer **104** (although, alternatively, the entire first isolating region **108** may be above the base layer **104**). Further, a top surface T_{108} of the first isolating region **108** may be horizontally aligned with a top surface T_{106} of the Hall plate region **106**. Accordingly, the first isolating region **108** may completely surround sides S_{106} of the Hall plate region **106**. The first isolating region **108** may include a deep trench isolation (DTI) structure, and may include an electrically insulating material, such as, but not limited to polysilicon. A thickness D_{108} of the first isolating region **108** may range from about 1 um to about 3 um, and may be about 2 um in a non-limiting embodiment.

As shown in FIGS. **1**A to **1**C, the sensor structure **102** may further include a plurality of second isolating regions **110***a*-**110***f* arranged within the Hall plate region **106**, and along the top surface T_{106} of the Hall plate region **106**. As more clearly shown in FIG. **1**B, the second isolating regions **110***a*-**110***f* may extend substantially parallel to one another. In particular, the second isolating regions **110***a*-**110***f* may extend across a width W_{106} of the Hall plate region **106**, such that at least one second isolating region **110***a*-**110***f* may contact the first isolating region **108** at one or both ends of the width W_{106}. For example, as shown in FIG. **1**B, each second isolating region **110***a*-**110***f* may contact the first isolating region **108** at both ends of the width W_{106}. Alternatively, one or more second isolating regions **110***a*-**110***f* may not contact the first isolating region **108**, or may contact the first isolating region **108** at only one end of the width W_{106}. Each second isolating region **110***a*-**110***f* may include a shallow trench isolation (STI) structure, and may include an electrically insulating material, such as, but not limited to a dielectric material. For example, the second isolating regions **110***a*-**110***f* may include gap fill oxide or nitride, or a combination of both. A thickness D_{110} of each second isolating region **110***a*-**110***f* may be smaller than the thickness D_{108} of the first isolating region **108**. Accordingly, while the first isolating region **108** may contact the base layer **104**, the second isolating regions **110***a*-**110***f* may not. The thickness D_{110} of each second isolating region **110***a*-**110***f* may be equal to or greater than 0.4 um. As shown in FIG. **1**C, the second isolating regions **110***a*-**110***f* in the device **100** may have a same thickness D_{110} but in alternative embodiments, the second isolating regions **110***a*-**110***f* may have different thicknesses.

The sensor structure **102** may further include a plurality of terminal regions including first to fifth terminal regions **112***a*-**112***e* arranged within the Hall plate region **106**. The plurality of terminal regions **112***a*-**112***e* may also be arranged along the top surface T_{106} of the Hall plate region **106**. In particular, each terminal region **112***a*-**112***e* may be arranged between two second isolating regions **110***a*-**110***f*, and therefore, each neighboring pair of terminal regions **112***a*-**112***e* may be electrically isolated from each other by one of the second isolating regions **110***a*-**110***f*. As shown in FIG. **1**C, the plurality of terminal regions **112***a*-**112***e* may adjoiningly alternate with the plurality of second isolating regions **110***a*-**110***f*. In other words, each terminal region **112***a*-**112***e* may adjoin the second isolating regions **110***a*-**110***f* it is arranged between. As more clearly shown in FIG. **1**B, the terminal regions **112***a*-**112***e* may extend substantially parallel to one another and to the second isolating regions **110***a*-**110***f*. Similar to the second isolating regions **110***a*-**110***f*, the terminal regions **112***a*-**112***e* may also extend across the width W_{106} of the Hall plate region **106**, such that at least one terminal region **112***a*-**112***e* may contact the first isolating region **108** at one or both ends of the width W_{106}. For example, as shown in FIG. **1**B, each terminal region **112***a*-**112***e* may contact the first isolating region **108** at both ends of the width W_{106}. Alternatively, one or more terminal regions **112***a*-**112***e* may not contact the first isolating region **108** or may contact the first isolating region **108** at only one end of the width W_{106}.

The plurality of second isolating regions **110***a*-**110***f* may extend deeper into the Hall plate region **106** than the plurality of terminal regions **112***a*-**112***e*. In other words, a thickness D_{112} of each terminal region **112***a*-**112***e* may be smaller than the thickness D_{110} of each second isolating region **110***a*-**110***f*. The thickness D_{112} of each terminal region **112***a*-**112***e* may range from about 0.1 um to about 1.5 um. As shown in FIG. **1**C, the terminal regions **112***a*-**112***e* in the device **100** may have a same thickness D_{112}, but in alternative embodiments, the terminal regions **112***a*-**112***e* may have different thicknesses.

As shown in FIGS. **1**A to **1**C, the first and fifth terminal regions **112***a*, **112***e* may be spaced apart from the first isolating region **108** by respective second isolating regions **110***a*, **110***f*, where these second isolating regions **110***a*, **110***f* may adjoin the first isolating region **108** along the width W_{106} of the Hall plate region **106**. Alternatively, the second isolating regions **110***a*, **110***f* in the device **100** may be omitted, and the first and fifth terminal regions **112***a*, **112***e* may adjoin the first isolating region **108** along the width W_{106} of the Hall plate region **106**. Further, while five terminal regions **112***a*-**112***e* and six second isolating regions **110***a*-**110***f* are depicted in FIGS. **1**A to **1**C, more or less of each region may be included.

In the device **100**, each of the terminal regions **112***a*-**112***e* may have a single conductivity type. In particular, the terminal regions **112***a*-**112***e* and the Hall plate region **106** may have a same conductivity type (the second conductivity type). In other words, when the base layer **104** includes p-type dopants, the Hall plate region **106** and the terminal regions **112***a*-**112***e* may include n-type dopants; and when the base layer **104** includes n-type dopants, the Hall plate region **106** and the terminal regions **112***a*-**112***e* may include p-type dopants. The p-type dopants may include boron (B), aluminum (Al), indium (In), or combinations thereof; whereas, the n-type dopants may include phosphorous (P), arsenic (As), antimony (Sb), or combinations thereof. The Hall plate region **106** may be more heavily doped (in other words, may include a higher dopant concentration (number of dopants per unit volume)) than the base layer **104**; whereas, the terminal regions **112***a*-**112***e* may be more heavily doped than the Hall plate region **106**. For example, the base layer **104** may have a dopant concentration ranging from about 1e15 cm^{-3} to about 1e16 cm^{-3}, and each terminal region **112***a*-**112***e* may have a dopant concentration ranging from about 1e19 cm^{-3} to about 1e20 cm^{-3}.

Each of the terminal regions **112***a*-**112***e* may be configured to electrically connect to an external device. The external device may be configured to provide a current through the Hall plate region **106** (e.g. the external device may be an external voltage source) or may be configured to determine a Hall voltage produced in the Hall plate region **106**. For example, FIG. **2** shows the device **100** with the first, third and fifth terminal regions **112***a*, **112***c*, **112***e* electrically connected to external voltage sources. The second and fourth terminal regions **112***b*, **112***d* may be connected to an external device (not shown in FIG. **2**) to determine the Hall voltage. In other words, the first, third and fifth terminal regions **112***a*, **112***c*, **112***e* may serve as current terminal regions; whereas, the second and fourth terminal regions **112***b*, **112***d* may serve as sensing terminal regions. Note that the dimensions D_{108}, D_{110}, D_{112}, surfaces T_{106}, T_{108} and sides S_{106} are not labelled in FIG. **2** to avoid cluttering the figure.

In particular, as shown in FIG. **2**, the first and fifth terminal regions **112***a*, **112***e* may be connected to a ground voltage GND (in other words, 0V); whereas, the third terminal region **112***c* may be connected to an external voltage V1 larger than the ground voltage GND. Depending on the technology used to fabricate the Hall effect sensor device **100**, the external voltage V1 may range from about 1V to about 6V. Due to the voltage differences between the first and third terminal regions **112***a*, **112***c* and between the third and fifth terminal regions, **112***c*, **112***e*, first and second currents **202**, **204** including charge carriers may flow through the Hall plate region **106** in opposite directions. In particular, the first current **202** may flow from the third terminal region **112***c* to the first terminal region **112***a*; whereas, the second current **204** may flow from the third terminal region **112***c* to the fifth terminal region **112***e*. In the presence of a magnetic field **206** perpendicular to the plane of the Hall plate region **106** (in other words, into the paper and perpendicular to the flow of the currents **202**, **204** as shown in FIG. **2**), Lorentz forces may be exerted on the charge carriers of the first and second currents **202**, **204** in opposite vertical directions **208**. A voltage difference (or in other words, a Hall voltage) may thus be produced between the second and fourth terminal regions **112***b*, **112***d*, and may be determined by the external device to which these terminal regions **112***b*, **112***d* are connected. The Hall voltage may be proportional to the strength of the magnetic field **206**, and thus, by determining the Hall voltage, the strength of the magnetic field **206** may be determined.

The terminal regions **112***a*-**112***e* may be connected to external devices in a manner different from that described with reference to FIG. **2**. For example, the fourth terminal region **112***d* and the second terminal region **112***b* may be connected to a ground voltage GND and an external voltage (similar to the above-mentioned V1), respectively; whereas, the first, third and fifth terminal regions **112***a*, **112***c*, **112***e* may be connected to an external device to measure the Hall voltage produced in the Hall plate region **106**. The first and fifth terminal regions **112***a*, **112***e* may be tied to a same connector of the external device.

The first and second isolating regions **108**, **110***a*-**110***f* in the device **100** may help to restrict the amount of change in the sizes and shapes of the Hall plate region **106** and the terminal regions **110***a*-**110***e*. Further, since there may be fewer p-n junctions in the Hall plate region **106** of the device **100** as compared to prior art Hall effect sensor devices, the performance of the device **100** may be less sensitive to temperature changes around the Hall plate region **106**, dopant variations in different terminal regions **112***a*-**112***e* and external voltages applied to the Hall plate region **106**. In turn, the resistance mismatch between different regions within the Hall plate region **106** may be lower and the offset voltage of the device **100** may be reduced. In addition, by surrounding the Hall plate region **106** with the first isolating region **108** and the base layer **104**, flow of the currents **202**-**204** may be better confined within the Hall plate region **106**.

To further reduce the offset voltage, a spinning current technique may be applied when using the device **100**. In this technique, the device **100** may be operated in four modes. In the first and second modes, the first, third and fifth terminal regions **112***a*, **112***c*, **112***e* may serve as current terminal regions; whereas, the second and fourth terminal regions **112***b*, **112***d* may serve as sensing terminal regions. In particular, in the first mode, the first and fifth terminal regions **112***a*, **112***e* may be connected to a ground voltage GND, and the third terminal region **112***c* may be connected to an external voltage **V1**. In the second mode, the first and fifth terminal regions **112***a*, **112***e* may be connected to an external voltage **V1**, and the third terminal region **112***c* may be connected to a ground voltage GND, so that the flow of currents through the Hall plate region **106** in the second mode may be opposite from those in the first mode. In the third and fourth modes, the first, third and fifth terminal regions **112***a*, **112***c*, **112***e* may serve as sensing terminal regions; whereas, the second and fourth terminal regions **112***b*, **112***d* may serve as current terminal regions. In particular, in the third mode, the second terminal region **112***b* may be connected to a ground voltage GND and the fourth terminal region **112***d* may be connected to an external voltage **V1**; whereas, in the fourth mode, the second terminal region **112***b* may be connected to an external voltage **V1** and the fourth terminal region **112***d* may be connected to a ground voltage GND. The Hall voltage may be determined in each mode and the final Hall voltage of the device **100** may be obtained using an average of the Hall voltages determined in the four modes. Averaging the Hall voltages in the four modes may help to filter away at least a part of the offset voltage of the device **100** from the final Hall voltage. Accordingly, the resulting offset voltage of the device **100** may be reduced.

The Hall effect sensor device **100** may be formed with existing technology without using additional mask layers. FIG. **3** shows a flow chart illustrating a method **300** for forming the device **100** according to various non-limiting embodiments.

Referring to FIG. **3**, at **302**, a substrate having the first conductivity type may be provided and at **304**, the base layer **104** and the first isolating region **108** may be formed within the substrate. The base layer **104** and the first isolating region **108** may be formed by any method as known to those skilled in the art. For example, the substrate may be etched to form a vertical opening extending partially through the substrate. The vertical opening may then be filled with electrically insulating material to form the first isolating region **108** and the substrate under the vertical opening may serve as the base layer **104**.

At **306**, the Hall plate region **106** may be formed above the base layer **104**, such that the first isolating region **108** is arranged around and adjoining the Hall plate region **106**. The Hall plate region **106** may be formed by doping a region of the substrate surrounded by the first isolating region **108** with dopants of the appropriate conductivity type.

At **308**, the second isolating regions **110***a*-**110***f* may be formed within the Hall plate region **106**. This may be done by etching the Hall plate region **106** to form a plurality of openings, and depositing electrically insulating material into these openings.

At **310**, the terminal regions **112***a*-**112***e* may be formed within the Hall plate region **106**. This may be done by doping areas between the second isolating regions **110***a*-**110***f* with dopants of the appropriate conductivity type.

The above described order for the method is only intended to be illustrative, and the method is not limited to the above specifically described order unless otherwise specifically stated. In addition, the Hall effect sensor device **100** may be implemented as part of an integrated circuit, and the method may further include other processes as known to those skilled in the art, for example, processes for forming transistors, and/or back-end-of-line (BEOL) processes for forming inter-layer-dielectric (ILD) layers and contacts.

FIG. **4** shows a Hall effect sensor device **400** according to alternative non-limiting embodiments. The semiconductor device **400** is similar to the semiconductor device **100**, and thus, the common features are labelled with the same reference numerals and need not be discussed.

Referring to FIG. **4**, as compared to the device **100**, the base layer **402** of the device **400** may instead include an insulating layer. This insulating layer may include insulating material that may minimize (or in a non-limiting example, fully restrict) current flow from the Hall plate region **106** through the base layer **402**. For example, the base layer **402** may include a buried oxide layer and the insulating material may include silicon dioxide. The insulating layer may also help to further isolate the Hall plate region **106** from neighboring components/structures, particularly, those under the Hall plate region **106**. Although not shown in FIG. **4**, the device **400** may further include a semiconductor substrate similar to the base layer **104** of the device **100** and the base layer **402** may be arranged within this semiconductor substrate. However, this semiconductor substrate may be omitted. Alternatively, further layers may be arranged between the base layer **402** and the semiconductor substrate. In use, the device **400** may operate in a manner similar to that described above for the device **100**.

FIG. **5**A shows a simplified top view of a Hall effect sensor device **500** according to alternative non-limiting embodiments, and FIG. **5**B shows a simplified cross-sectional view of the device **500** along the line B-B' of FIG. **5**A. The device **500** may include further sensor structures. In particular, the device **500** may include a plurality of sensor structures including a first sensor structure **502**, a second sensor structure **504**, a third sensor structure **506** and a fourth sensor structure **508**. Each of these sensor structures **502**, **504**, **506**, **508** is similar to the sensor structure **102** of the semiconductor device **100**, and thus, the common features are labelled with the same reference numerals and need not be discussed. Note however that to avoid cluttering the figures, the dimensions W_{106}, D_{108}, D_{110}, D_{112}, surfaces T_{106}, T_{108} and sides S_{106} are not labelled in FIGS. **5**A and **5**B. Further, although four sensor structures are shown, the number of sensor structures in the Hall effect sensor device **500** may be greater than or less than four.

Referring to FIGS. **5**A and **5**B, as compared to the sensor structure **102** of the semiconductor device **100**, each sensor structure **502**-**508** of the device **500** may include fewer terminal regions **112***a*-**112***c* and second isolating regions **110***a*-**110***d*. In particular, each sensor structure **502**-**508** may include only a first terminal region **112***a*, a second terminal region **112***b* and a third terminal region **112***c*. The sensor structures **502**-**508** in the semiconductor device **500** may be electrically connected to one another using connectors **550**. The connectors **550** may include an electrically conductive material, such as, but not limited to aluminum, copper, tungsten, alloys thereof or combinations thereof. For example, the connectors **550** may include electrical wires. As shown in FIG. **5**A, the first, second, third and fourth sensor structures **502**, **504**, **506**, **508** may be arranged along a same axis (along the line B-B') of FIG. **5**A and may be connected in said order in series. In particular, the first terminal region **112***a* of the first sensor structure **502** may be electrically connected with the third terminal region **112***c* of the fourth sensor structure **508**. Further, the third terminal regions **112***c* of the first, second and third sensor structures **502**, **504**, **506** may be electrically connected with the first terminal regions **112***a* of the second, third and fourth sensor structures **504**, **506**, **508** respectively.

FIG. **6** shows the Hall effect sensor device **500** in use with the second terminal region **112***b* of the first sensor structure **502** connected to an external voltage V1 (similar to the V1 in FIG. **2**), and the second terminal region **112***b* of the third sensor structure **506** connected to a ground voltage GND. The second terminal regions **112***b* of the second and fourth sensor structures **504**, **508** may be connected to an external device (not shown in FIG. **6**) to determine a Hall voltage through the device **500**. In other words, the second terminal regions **112***b* of the first and third sensor structures **502**, **506** may serve as current terminal regions, and the second terminal regions **112***b* of the second and fourth sensor structures **504**, **508** may serve as sensing terminal regions.

As shown in FIG. **6**, due to the voltage difference between the second terminal regions **112***b* of the first and third sensor structures **502**, **506**, first to sixth currents **510**-**520** including charge carriers may flow through the Hall plate regions **106** of the sensor structures **502**-**508**. In particular, the first and second currents **510**, **512** may flow in opposite directions through the Hall plate region **106** of the first sensor structure **502**, with the first current **510** flowing from the second terminal region **112***b* to the first terminal region **112***a*, and the second current **512** flowing from the second terminal region **112***b* to the third terminal region **112***c*. The third current **514** may flow through the Hall plate region **106** of the second sensor structure **504** from the first terminal region **112***a* to the third terminal region **112***c*. Similar to the first and second currents **510**, **512**, the fourth and fifth currents **516**, **518** may flow in opposite directions through the Hall plate region **106** of the third sensor structure **506**. However, the fourth current **516** may flow from the first terminal region **112***a* to the second terminal region **112***b*; whereas, the fifth current **518** may flow from the third terminal region **112***c* to the second terminal region **112***b*. Further, the sixth current **520** may flow from the third terminal region **112***c* to the first terminal region **112***a* through the Hall plate region **106** of the fourth sensor structure **508**.

In the presence of a magnetic field **522** perpendicular to the planes of the Hall plate regions **106** (into the paper and perpendicular to the flow of the first to sixth currents **510**-**520** as shown in FIG. **6**), Lorentz forces may be exerted on the charge carriers of the third and sixth currents **514**, **520** in opposite vertical directions **524**. A voltage difference (or in other words, a Hall voltage) may thus be produced between the second terminal regions **112***b* of the second and fourth sensor structures **504**, **508**, and may be determined by the external device to which these terminal regions **112***b* are connected. The Hall voltage may be proportional to the strength of the magnetic field **522**, and thus, the device **500** may determine the strength of the magnetic field **522** based on the Hall voltage.

FIG. **7** shows a simplified top view of a Hall effect sensor device **700** according to alternative non-limiting embodiments. The device **700** is similar to the device **600**, and thus, the common features are labelled with the same reference numerals and need not be discussed.

Referring to FIG. **7**, the device **700** may also include a plurality of sensor structures including first, second, third and fourth sensor structures **502**, **504**, **506**, **508** similar to those of the device **600**. However, as compared to the device **600**, the sensor structures **502**-**508** of the device **700** may not be arranged along a same axis but may instead be arranged in a cross configuration. In particular, as shown in FIG. **7**, the first and third sensor structures **502**, **506** may be arranged along a first axis Y-Y'; whereas, the second and fourth sensor structures **504**, **508** may be arranged along a second axis X-X' perpendicular to the first axis Y-Y'. The sensor structures **502**-**508** may similarly be electrically connected to one another using connectors **550**. In particular, the first, second, third and fourth sensor structures **502**-**508** may be connected in said order in series. As shown in FIG. **7**, the third terminal region **112***c* of the first sensor structure **502** may be connected to the first terminal region **112***a* of the second sensor structure **504**, the third terminal region **112***c* of the second sensor structure **504** may be connected to the third terminal region **112***c* of the third sensor structure **506**, the first terminal region **112***a* of the third sensor structure **506** may be connected to the first terminal region **112***a* of the fourth sensor structure **508**, and the third terminal region **112***c* of the fourth sensor structure **508** may be connected to the first terminal region **112***a* of the first sensor structure **502**. This connection of the sensor structures **502**-**508** in the device **700** may allow the device **700** to detect strengths of magnetic fields parallel to the X-X' axis. Alternatively, the sensor structures **502**-**508** may be connected in a different manner to detect strengths of magnetic fields parallel to other axes (e.g. the Y-Y' axis), or may be connected to switching elements configured to change the connections of the sensor structures **502**-**508** according to the directions of the magnetic fields whose strengths are to be determined.

The flow of the currents through the devices **500** and **700** may be more symmetrical, as compared to that through the device **100**. This may be because as shown in FIG. **6**, when the device **500** is in use, the flow of the current(s) **510**-**520** in each sensor structure **502**-**508** may be similar to that in another sensor structure **502-508**, except that the direction(s) of the current(s) **510-520** may be opposite. For example, in both the first and third sensor structures **502**, **506**, the currents **510**, **512**, **516**, **518** flow between the second terminal region **112***b* and the first/third terminal region **112***a*, **112***c*, but the currents **510**, **512** in the first sensor structure **502** may be in opposite directions from those in the third sensor structure **506**. Similarly, in both the second and fourth sensor structures **504**, **508**, the currents **514**, **520** flow between the first and third terminal regions **112***a*, **112***c*, but in opposite directions.

The invention may be embodied in other specific forms without departing from the spirit or essential characteristics thereof. The foregoing embodiments, therefore, are to be considered in all respects illustrative rather than limiting the invention described herein. Scope of the invention is thus indicated by the appended claims, rather than by the foregoing description, and all changes that come within the meaning and range of equivalency of the claims are intended to be embraced therein.

The invention claimed is:

1. A Hall effect sensor device comprising a sensor structure, wherein the sensor structure comprises:

a base layer having a first conductivity type;

a Hall plate region having a second conductivity type opposite from the first conductivity type arranged above the base layer;

a first isolating region arranged around and adjoining the Hall plate region, wherein the first isolating region comprises an electrically insulating material and contacts the base layer;

a plurality of second isolating regions arranged within the Hall plate region, wherein each of the plurality of second isolating regions comprises an electrically insulating material; and

a plurality of terminal regions arranged within the Hall plate region, each neighboring pair of terminal regions electrically isolated from each other by one of the plurality of second isolating regions,

wherein the plurality of terminal regions adjoiningly alternate with the plurality of second isolating regions.

2. The Hall effect sensor device of claim **1**, wherein the plurality of second isolating regions extend deeper into the Hall plate region than the plurality of terminal regions.

3. The Hall effect sensor device of claim **1**, wherein the first isolating region completely surrounds sides of the Hall plate region.

4. The Hall effect sensor device of claim **1**, wherein the first isolating region extends partially into the base layer.

5. The Hall effect sensor device of claim **1**, wherein the plurality of second isolating regions extend across a width of the Hall plate region, such that at least one second isolating region of the plurality of second isolating regions contacts the first isolating region at one or both ends of the width.

6. The Hall effect sensor device of claim **1**, wherein the plurality of terminal regions extends across a width of the Hall plate region, such that at least one terminal region of the plurality of terminal regions contacts the first isolating region at one or both ends of the width.

7. The Hall effect sensor device of claim **1**, wherein the plurality of terminal regions extend substantially parallel to one another across a width of the Hall plate region.

8. The Hall effect sensor device of claim **1**, wherein the plurality of second isolating regions and the plurality of terminal regions are arranged along a top surface of the Hall plate.

9. The Hall effect sensor device of claim **1**, wherein a top surface of the first isolating region is horizontally aligned with a top surface of the Hall plate region.

10. The Hall effect sensor device of claim **1**, wherein the first isolating region comprises a deep trench isolation structure and the plurality of second isolating regions comprise shallow trench isolation structures.

11. The Hall effect sensor device of claim **1**, wherein the plurality of terminal regions and the Hall plate region have a same conductivity type.

12. The Hall effect sensor device of claim **1**, wherein the plurality of terminal regions are more heavily doped than the Hall plate region.

13. The Hall effect sensor device of claim **1**, wherein the Hall effect sensor device comprises a single sensor structure.

14. The Hall effect sensor device of claim **1**, wherein the Hall effect sensor device comprises further sensor structures, wherein the sensor structure and the further sensor structures are electrically connected to one another.

15. The Hall effect sensor device of claim **14**, wherein the sensor structure and the further sensor structures comprise a first sensor structure, a second sensor structure, a third sensor structure and a fourth sensor structure electrically connected in said order in series, wherein the first sensor structure and the third sensor structure are arranged along a first axis, and wherein the second sensor structure and the fourth sensor structure are arranged along a second axis perpendicular to the first axis.

16. The Hall effect sensor device of claim **1**, wherein the plurality of second regions are each distinct regions and are dielectric.

17. The Hall effect sensor device of claim **1**, wherein the first sensor structure, the second sensor structure, the third sensor structure and the fourth sensor structure each comprises a first, second, third and fourth second isolating regions and a first, second and third terminal regions.

18. The Hall effect sensor device of claim **17**, wherein the first terminal region of the first sensor structure is connected to the third terminal region of the fourth sensor structure, the third terminal region of the first sensor structure is connected to the first terminal region of the second sensor structure, the third terminal region of the second sensor structure is connected to the third terminal region of the third sensor structure, and the first terminal region of the third sensor structure is connected to the first terminal region of the fourth sensor structure.

19. A method of forming a Hall effect sensor device, wherein the method comprises:

providing a substrate having a first conductivity type;

forming a base layer having the first conductivity type and a first isolating region comprising an electrically insulating material within the substrate, wherein the first isolating region contacts the base layer;

forming a Hall plate region having a second conductivity type opposite from the first conductivity type above the base layer, wherein the first isolating region is arranged around and adjoining the Hall plate region;

forming a plurality of second isolating regions within the Hall plate region, wherein each of the plurality of second isolating regions comprises an electrically insulating material; and

forming a plurality of terminal regions within the Hall plate region, each neighboring pair of terminal regions electrically isolated from each other by one of the plurality of second isolating regions,

wherein the plurality of terminal regions adjoiningly alternate with the plurality of second isolating regions.

20. A Hall effect sensor device comprising a sensor structure, wherein the sensor structure comprises:

an insulating layer;

a Hall plate region arranged above the insulating layer;

a first isolating region arranged around and adjoining the Hall plate region, wherein the first isolating region comprises an electrically insulating material and contacts the insulating layer;

a plurality of second isolating regions arranged within the Hall plate region, wherein each of the plurality of second isolating regions comprises an electrically insulating material; and

a plurality of terminal regions arranged within the Hall plate region, each neighboring pair of terminal regions electrically isolated from each other by one of the plurality of second isolating regions,

wherein the plurality of terminal regions adjoiningly alternate with the plurality of second isolating regions.

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